

# Can low metallicity binaries avoid merging?

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**Abstract.** Rapid mass transfer in a binary system can drive the accreting star out of thermal equilibrium, causing it to expand. This can lead to a contact system, strong mass loss from the system and possibly merging of the two stars. In low metallicity stars the timescale for heat transport is shorter due to the lower opacity. The accreting star can therefore restore thermal equilibrium more quickly and possibly avoid contact.

We investigate the effect of accretion onto main sequence stars with radiative envelopes with different metallicities. We find that a low metallicity ( $Z < 10^{-3}$ )  $4M_{\odot}$  star can endure a 10 to 30 times higher accretion rate before it reaches a certain radius than a star at solar metallicity. This could imply that up to two times fewer systems come into contact during rapid mass transfer when we compare low metallicity. This factor is uncertain due to the unknown distribution of binary parameters and the dependence of the mass transfer timescale on metallicity. In a forthcoming paper we will present analytic fits to models of accreting stars at various metallicities intended for the use in population synthesis models.

**Keywords:** binaries, mass transfer, metallicity, contact systems, accretion, radii

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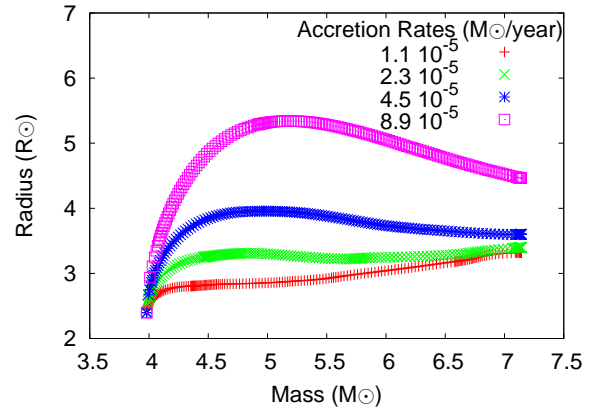
## INTRODUCTION

The majority of stars are found in binaries, many of which can interact, for example by exchanging mass, resulting in an evolution very distinct from isolated stars. Although the fraction of stars in binaries might be different for earlier generations of stars, formed in metal-poor environments, they are certainly worth a systematic study. In this work we discuss the effect of accretion onto main sequence stars as function of metallicity. In a second contribution to these proceedings we discuss how the ranges for different cases of mass transfer depend on metallicity [1].

Mass transfer takes place when one of the stars exceeds a certain critical radius, the Roche lobe radius. The first phase of mass transfer is usually so fast that the accreting star is driven out of thermal equilibrium and expands [2, 3], potentially so much that the two stars come into contact. Contact binaries are not well understood, but they probably involve strong mass loss from the system and merging of the two stars.

Instead of using full binary evolution models, we choose to reduce the large parameter space of binaries by studying the behavior of models of isolated stars under controlled conditions. We follow the approach of Kippenhahn and Meyer-Hofmeister [4] and Neo et al. [5], who studied the evolution of the radius of accreting main sequence stars. We extend their work, to study the effect of metallicity, using up-to-date input physics.

Here we present the results of an exploratory study and its possible implications for binaries at low metallicity. In a forth coming paper we will present analytic fits to a



**FIGURE 1.** Radius versus mass of an initially  $4 M_{\odot}$  star at solar metallicity accreting with different accretion rates.

finer grid of models, intended for the use in population synthesis models. Expansion due to thermal timescale mass transfer is commonly neglected or taken into account using a simple approximate criterion. Our fits will provide an improvement, which is easy to implement.

## EVOLUTION CODE

We use the fully implicit stellar evolution code STARS, originally developed by Peter Eggleton [6, 7, 8], updated with the latest opacity tables [9, 10, 11]. For the hydrogen and helium abundance we assume a linear relation with  $Z$ :  $X = 0.76 - 3.0Z$  and  $Y = 0.24 + 2.0Z$ . The abundances

of the heavier elements are assumed to scale to solar and meteoric abundances [12] so that they are consistent with the opacity tables. A mixing length ratio  $l/H_p = 2.0$  is assumed. Convective overshooting is taken into account as in Schröder et al. [13] with a free parameter  $\delta_{ov} = 0.12$  calibrated against accurate stellar data from non-interacting binaries [14].

We assume that material is accreted in a spherically symmetric way at a constant rate onto a zero age main sequence star with a composition and specific entropy equal to the surface value.

## RESULTS

Figure 1 shows as an example the radius versus mass  $M$ , which increases linearly with time, of an initially  $4M_\odot$  star at solar metallicity ( $Z = 0.02$ ) accreting at different rates. At an accretion rate of  $8.9 \cdot 10^{-5} M_\odot/\text{yr}$  the star expands to more than twice its original radius after accreting  $1M_\odot$  before it shrinks again towards its thermal equilibrium radius  $R_{eq}(M)$ . If the accretion rate is low, for example  $1.1 \cdot 10^{-5} M_\odot/\text{yr}$ , the radius of the star remains close to its equilibrium radius. The equilibrium radius  $R_{eq}(M)$  increases with the mass of the star. We define  $R_{max}$ , as the radius of the star when  $R/R_{eq}(M)$  is at maximum, so that it represents the radius at the moment the star is driven furthest out of thermal equilibrium.

The effect of the metallicity on  $R_{max}$  is shown in Figure 2. The maximum radius increases by more than a factor of two if we compare low metallicity ( $Z < 10^{-3}$ ) to solar metallicity. Especially in the range  $Z > 10^{-3}$  the effect becomes important.

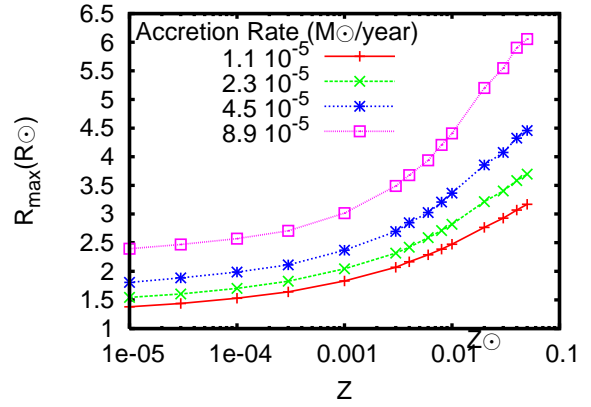
In order to expand to a radius of  $2.5R_\odot$  a low metallicity star needs to accrete approximately  $8.9M_\odot/\text{yr}$ , while a solar metallicity will expand to this radius when it accretes  $1.1M_\odot/\text{yr}$ , see Fig. 2.

From our models we estimate that a star can endure a 10 to 30 times higher accretion rate, comparing low to solar metallicity before its radius exceeds a certain critical radius, say the Roche lobe radius.

This effect can be understood by considering the timescale for heat transport  $\tau_h$  [5, eq. 10]

$$\tau_h = \frac{3C_p \kappa \rho^2 H_p^2}{4acT^3}$$

over one scale height of pressure  $H_p$ , where  $C_p$  and  $\kappa$  denote the specific heat and opacity. In metal rich stars, heavy elements like C, O, N and Fe provide an important contribution to the opacity, increasing the timescale for heat transport. At low metallicity stars can radiate away any excess energy on a shorter timescale, to restore thermal equilibrium.



**FIGURE 2.** The maximum radius during accretion (for definition see text) is plotted versus metallicity for a  $4M_\odot$  star accreting at different rates.

## IMPLICATIONS

In this paragraph we will speculate on the possible implications of our findings for binary stars. In binaries with nearly equal masses contact during rapid mass transfer is avoided, as the time scale for mass transfer, which is of the order of the thermal time scale of the donor, is of the same order as the time scale on which the accreting star can restore its thermal equilibrium. If the mass ratio  $q = M_a/M_d$  is smaller than a certain critical value  $q_{crit}$  the systems do get into contact. For solar metallicity  $q_{crit} \approx 0.56$  [15], for close systems in the mass range of our models. From our results we can roughly estimate how  $q_{crit}$  changes with metallicity.

If we assume that the mass transfer rate in a binary can be approximated by the mass of the donor  $M_d$  over the thermal timescale of the donor star  $\tau_{KH} = GM^2/RL \approx M^\alpha$ , where  $\alpha = 2.7..2.9$ , then a 10 to 30 times higher critical accretion rate corresponds to a donor which is at least twice as massive. Therefore  $q_{crit}$  will be a factor 2 smaller at low metallicity.

If we make the commonly used assumption that the initial distribution of mass ratios is flat in  $q$ , and that the distributions do not depend on metallicity and if we assume that the mass transfer rate does not depend on the metallicity, nor the binary parameters, then our result implies that the number of systems that come into contact during rapid mass transfer at low metallicity is half of that at solar metallicity.

## CONCLUSIONS

We find that a  $4M_\odot$  low metallicity star ( $Z < 10^{-3}$ ) can endure a 10 to 30 times higher accretion rate before it expands to a certain radius compared to solar metallicity

stars.

This suggests that at low metallicity fewer binaries come into contact during rapid mass transfer. A rough estimate based on very simplified assumptions indicate that the effect could be up to a factor 2, i.e. only half as many may binaries evolve into contact at low metallicity ( $Z < 10^{-3}$ ) compared to solar metallicity.

This factor is uncertain and probably only an upper limit as it depends on the initial distribution of binary parameters, on how the typical mass transfer rate depends on metallicity [it is probably higher at low metallicity, e.g. 16] and the binary parameters, on the specific entropy of the accreted material and on the efficiency of mass transfer [see for example 17].

In a forthcoming paper we will present analytic fits to our models intended for the use in population synthesis models.

## ACKNOWLEDGMENTS

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